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PATENT
KEL01 P-134

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Jan Antonis
Serial No.	:	10/822,476
Filed	:	April 12, 2004
For	:	INSPECTION SYSTEM AND METHOD

Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Dear Sir:

CLAIM OF PRIORITY

Applicant hereby claims the priority benefits under the provisions of 35 U.S.C. 119, basing said claim of priority on United Kingdom patent Application No. 0308509.9, filed April 12, 2003.

In accordance with the provisions of 35 U.S.C. 119 and 37 C.F.R. 1.55(a), certified copies of the above listed United Kingdom patent application is attached.

Respectfully submitted,

JAN ANTONIS

By: Van Dyke, Gardner, Linn & Burkhart, LLP

Dated: May 4, 2004

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P.O. Box 1450
Alexandria VA 22313-1450

Dear Sir:

CERTIFICATE OF MAIL

I certify that the attached return postcard, Claim of Priority, and a Certified Copy of UK Application No. 0308509.9 are being deposited with the United States Postal Service as first class mail in an envelope addressed to:

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on May 4, 2004.

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1. Your reference — MOC/AW

2. Patent application number *(The Patent Office will fill in this part)* — 12 APR 2003 — 0308509.9

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

JAN ANTONIS
87 ULSTERVILLE GARDENS
BELFAST
BT9 7BB
NORTHERN IRELAND

08610156001

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

INSPECTION APPARATUS AND METHOD

5. Name of your agent *(if you have one)*

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
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11. I/~~We~~ request the grant of a patent on the basis of this application.

Signature [signature] Date 11/4/03

ALAN WALLACE, AGENT FOR JAN ANTONIS

12. Name and daytime telephone number of person to contact in the United Kingdom ALAN WALLACE 02890 236000

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INSPECTION APPARATUS AND METHOD

Field of the Invention

The present invention relates to the field of object inspection and image processing.

Background to the Invention

There are a wide variety of applications which call for the inspection of objects to determine or verify their dimensions. For example, during or after the manufacture of an object it may be necessary to verify the object's dimensions for quality control purposes. Alternatively, it may be desired to determine an object's dimensions for reverse engineering purposes.

Automatic inspection systems which employ digital cameras are well known, especially for inspecting generally planar objects such as sheet metal or printed circuit boards. The image data captured by a digital camera normally represents the object in two dimensions (2D). In order to generate three dimensional (3D) data describing an object, conventional inspection systems commonly employ more than one camera to capture 2D images of the object from more than one perspective and then use data processing software to assimilate the data gathered by each camera to produce 3D data. Alternatively, a conventional system may use a single camera arranged for movement relative to the object (or vice versa) so that a number of different 2D images may be captured from which 3D data can be assimilated.

One problem with conventional inspection systems of the type outlined above is that they are expensive. As a result, in many applications inspection is still performed manually using callipers or rulers.

It would be desirable, therefore to provide an inspection system which does not require multiple cameras or require that there is relative movement between the object and the camera.

Summary of the Invention

Accordingly, a first aspect of the invention provides an apparatus for processing an image of an object, the apparatus being arranged to receive a plurality of image data components, each image data component representing the position of a respective component of the object in two dimensions, the apparatus being further arranged to receive one or more object dimension data component and to associate the, or a respective, object dimension data component with each image data component to produce an object data component which represents the position of the respective component of the object in three dimensions.

Preferably, the apparatus is arranged to receive one object dimension data component and to associate it with each image data component. This corresponds to the case where the object is generally planar in shape. Typically, the object dimension data component relates to the thickness of the object, or the dimension of the object in a direction perpendicular to the object plane.

A second aspect of the invention provides a method of processing an image of an object, the method comprising: receiving a plurality of image data components, each image data component representing the position of a respective component of the object in two dimensions; receiving one or more object dimension data component; and associating the, or a respective, object dimension data component with each image data component to produce an object data component which represents the position of the respective component of the object in three dimensions.

A third aspect of the invention provides a computer program product comprising computer usable code for causing a computer to perform the method of the second aspect of the invention.

A fourth aspect of the invention provides a system for inspecting an object, the system comprising: a work surface providing an object plane on which, in use, the object to be inspected is located; and a camera arranged with respect to the work surface so that at least part of the work surface is within the camera's field of vision, the camera being further arranged to capture an image of an object located on the work surface, the image comprising a plurality of image data components, each image data component representing the position of a respective component of the object in two dimensions, wherein the system further includes the apparatus of the first aspect of the invention, arranged to receive image data components from said camera.

A fifth aspect of the invention provides an apparatus for processing an image of an object located on an object plane, the apparatus being arranged to receive a plurality of image data components, each image data component being associated with a detected edge of the object, the apparatus being arranged, in respect of each image data component, to project the image data component onto the object plane to obtain a corresponding object data component, to calculate a respective first parameter relating to a notional reference line extending from the object data component, to calculate a second parameter relating to a notional line extending between the object data component and a reference point in the object plane, and to compare the difference between said first parameter and said second parameter against a threshold value. This allows the apparatus to determine if the object data component relates to an upper edge or a lower edge of the object.

Preferably, said first parameter comprises the value of an angle between an angle reference axis and said notional reference line extending from the object data component. Preferably, said notional reference line extending from the object data component comprises a line which is normal, or substantially normal, to the detected edge of which the object data component forms part. Conveniently, the apparatus calculates said first parameter from a respective one or more other object data components which lie on each side of the object data component on the detected edge.

Preferably, said second parameter comprises the value of an angle between the angle reference axis and said notional reference line extending between the object data component and said reference point. Preferably, said reference point on the object plane comprises the point where a notional line projected from the camera's focal point perpendicularly with respect to the object plane intersects the object plane. Where the reference point comprises said projected focal point, the notional reference line extending between the object data component and said reference point is referred to herein as the radial line.

In the preferred embodiment, wherein said first parameter comprises the value of said angle of said normal line and said second parameter comprises the value of said angle of said radial line, said threshold value is 90 degrees. Preferably, the apparatus is arranged to determine that the object data component relates to a top edge if the absolute difference between said first and second parameters is greater than 90 degrees and that the object data component relates to a bottom edge if the absolute difference between said first and second parameters is less than 90 degrees.

A sixth aspect of the invention provides a method of processing an image of an object located on an object plane, the method including receiving a plurality of image data components, each image data component being associated with a detected edge of the object; and, in respect of each image data component, projecting the image data component onto the object plane to obtain a

corresponding object data component; calculating a respective first parameter relating to a notional reference line extending from the object data component; calculating a second parameter relating to a notional line extending between the object data component and a reference point in the object plane; and comparing the difference between said first parameter and said second parameter against a threshold value.

A seventh aspect of the invention provides a computer program product comprising computer usable code for causing a computer to perform the method of the sixth aspect of the invention.

An eighth aspect of the invention provides a system for inspecting an object, the system comprising: a work surface providing an object plane on which, in use, the object to be inspected is located; and a camera arranged with respect to the work surface so that at least part of the work surface is within the camera's field of vision, the camera being further arranged to capture an image of an object located on the work surface, wherein the system further includes the apparatus of the fifth aspect of the invention.

The invention in all its aspects is particularly suited for use with image data components corresponding to a respective point, or component, on an edge of the object. Preferably, the image data components are derived from a silhouette, or occluding contour, of the object and correspond with one or more detected edges of the object.

Further, the invention in all its aspects is particularly suited for inspecting generally planar objects such as, sheet metal, PCBs, cloth, cardboard, sheet plastics, or any other generally flat opaque objects, especially those that are punched or profiled.

Other advantageous aspects of the invention will become apparent to those skilled in the art upon review of the following description of a specific embodiment and with reference to the accompanying drawings.

Brief Description of the Drawings

A specific embodiment of the invention is now described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of an inspection apparatus embodying one aspect of the invention, the apparatus being located in situ above an object to be inspected;

Figure 2 is a flow chart illustrated the operation of the apparatus of Figure 1;

Figure 3 is an illustration of a polyline comprised of a plurality of object edge points;

Figure 4 is an illustration of edge examination of an inspected object; and

Figure 5 is an illustration of how to determine an actual edge point from a projected edge point.

Detailed Description of the Drawings

Referring now to Figure 1 of the drawings, there is shown, generally indicated as 10, an example of an inspection apparatus embodying the invention. The apparatus 10 comprises a digital camera 12 and a data processing system 14 (which is conveniently represented as a computer in Figure 1). The digital camera 12 is advantageously a high resolution camera wherein the resolution is in the order of at least 6 Megapixels. It will be understood that, in practice, the level of resolution required depends on the required accuracy of the results and/or on the size of the area to be inspected. The data processing system 14 is arranged to run a data processing module 16 in the form of, for example, a computer program. As is described in more detail below, the data processing module 16 is arranged to receive image data from the camera 12 and to generate 3D data 18 representing the inspected object. Depending on the requirements of the application, the generated 3D data 18 may be compared with expected 3D data 20 to produce an inspection report 22.

Figure 1 also shows an object 24 to be inspected. In the present example, the object 24 is assumed to be generally planar, or flat, and to have a plurality of apertures 26 formed therein. In particular, it is assumed that the object 24 is of generally uniform thickness T. The object 24 may be formed from any substantially opaque material such as metal, plastics,

wood, cardboard or paper. It will be understood that the specific size and shape of the illustrated object 24, and the number, size, shape and arrangement of apertures 26, is by way of example only.

The object 24 is located on the obverse face a work surface 28. In the preferred embodiment, the work surface 28 is illuminated from its reverse face by a light source 30. The work surface 28 is therefore formed from a translucent material and, more preferably, a material that diffuses light so that a substantially uniform illumination of the work surface 28 is achieved. By way of example, the work surface 28 may advantageously be formed from diffuse frosted glass, or the like.

The camera 12 is located over the work surface 28 such that any object placed on the obverse face of the work surface 28 is within its field of vision. The camera 12 has a focal point (not shown in Figure 1) and a normal line of sight 13, the normal line of sight being the line of sight from the focal point which is perpendicular to the camera's image plane. Preferably, the camera 12 is arranged with respect to the work surface so that the normal line of sight 13 of the camera 12 is substantially perpendicular to the work surface 28. While an image is being taken, the camera 12 is fixed with respect to the work surface 28 and may be held in a suitable fixed position by any suitable means, for example a gantry or other support structure (not shown).

The illuminated work surface 28 causes a silhouette, or occluding contour, of the object 24 to be presented to the camera 12 and so facilitates detection of the object's perimeters. It is not essential to illuminate the work surface 28. For example, providing the work surface 28 and the object 24 in respective contrasting colours or shades, the camera 12 can detect the outline of the object 24 using conventional colour separation techniques. The contrasted outline of the object 24 against the work surface 28, whether by silhouette or colour contrast, may be referred to as an occluding contour.

During use, the camera 12 captures an image of the object 24, the image data normally comprising a plurality of image data components in the form of pixels. Hence, the camera 12 is able to provide, to the data processing module 16, image data usually in the form of an electronic file, preferably of a lossless format such as a bitmap, or the like. It is not possible to generate 3D data, or a 3D model, of the object 24 using only a single image from a single static camera 12. This is primarily because the captured image data is essentially 2D data, i.e. the position of a given pixel of the image data in a plane substantially perpendicular to the camera's normal line of sight 13 (hereinafter the X-Y plane) can be determined, but its position in a plane substantially parallel to the camera's normal line of sight 13 (hereinafter the Z plane) cannot be determined. As can be seen from Figure 1, it is assumed that the work surface 28 lies substantially in an X-Y plane and the camera's normal line of sight 13 lies in a Z plane.

To address the problem outlined above, it is preferred that the inspection apparatus 10, and in particular the data processing module 16, is arranged for use with objects that are generally planar, of known thickness and which, during use, lie substantially in an X-Y plane. Hence, the data processing module 16 knows the dimension of the object 24 in the Z direction (i.e. its thickness T) and this enables the data processing module 16 to accord a 3D position (i.e. an X, Y and Z co-ordinate) to any given pixel.

However, there is a further problem to be addressed. As is well known, the outline or perimeters of an object can be determined from the captured image data using conventional edge detection or colour separation techniques. However, for 3D objects, it is not possible to determine from a single image whether a detected edge is an upper edge or a lower edge. This ambiguity prevents the generation of an accurate 3D model of the object.

The data processing module 16 is arranged to overcome this problem as described below with reference, in particular, to Figure 2 of the drawings. Figure 2, illustrates the processes performed by the data processing module 16. Block 200 represents receipt by the data processing module 16 of the captured image data from the camera 12. It is assumed in the present example that the image data is comprised of pixels. The captured image data comprises a representation of the 2D silhouette, or occluding contour, of the object 24 as viewed by the camera 12.

At block 202, the data processing module 16 employs conventional edge detection, or equivalent, techniques to detect the edges of the occluding contour of the captured image. In the present example, it is assumed that this is performed with single pixel accuracy (i.e. the presence of an edge is identified by the nearest whole pixel to the detected edge) although, depending on the level of accuracy required, it may alternatively be performed with sub-pixel or multi-pixel accuracy. In any event, once edge detection is completed, a plurality of 2D co-ordinate points (hereinafter referred to as image edge points IEPs) are identified which correspond to the detected edges of the occluded contour of the captured image. Where edge detection is performed with single pixel accuracy, each edge point IEP corresponds with a respective pixel of the captured image.

There are many suitable conventional edge detection techniques. The paper entitled "A Computational Approach to Edge Detection" by J. Canny in IEEE transactions on Pattern Analysis and Machine Intelligence, Volume 8, Issue 6, pp. 679-698 (ISSN: 0162-8828) describes a suitable edge detection technique.

Referring now to block 204, after edge detection, the image edge points IEPs are sorted into sets or groups according to which perimeter of the occluding contour they belong (for example, the perimeter corresponding to the exterior of the object 24 or the perimeter corresponding to one or other of the internal apertures

26). Further, within each set, the edge points IEP are arranged in order, or sequence, such that successive edge points with a respective set trace, or track, the respective perimeter (i.e. the edge points within a set are ordered so that they are adjacent their nearest neighbour(s) on the respective perimeter).

There are many conventional nearest neighbour algorithms which could be used to sort the edge points in the manner described. For example, the paper entitled "Topological Structural Analysis of Digital Binary Images by Border Following" by S. Suzuki and K. Abe in CVGIP, volume 30, n.1 1985, pp. 32-46, describes an example of a suitable technique.

It will be understood that the processes described for blocks 202 and 204 need not necessarily be performed separately. Some edge detection techniques automatically generate edge points which are ordered in the manner described above.

At this stage, the image edge point IEP co-ordinates relate to the image plane (not illustrated), or image co-ordinate system, of the camera 12. At block 206, however, the edge points IEP in the image plane are projected to the object plane, or World co-ordinate system, i.e. the reference plane in which the inspected object 24 lies, using conventional geometrical techniques and a knowledge of the camera's intrinsic parameters (such as focal length and lens distortion) and extrinsic parameters (such as position and orientation with respect to the object plane). A description of how this process may be performed may be

obtained from the paper entitled "A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses" by R.Y. Tsai published in the IEEE Journal of Robotics and Automation, Volume RA-3, No. 4, August 1987, pages 323-344.

In the present example, the object plane is assumed to correspond with the Z=0 plane, i.e. the X-Y plane in which the work surface 28 lies. Essentially, the edge points IEP in the camera's image plane are converted into projection angles, or lines of sight, from the image plane, through the camera's focal point, and onto the object plane.

Referring now to block 208, the respective points at which the projected lines of sight intersect the Z=0 plane (hereinafter referred to as object edge points OEPs) may be represented by respective 2D co-ordinates in the Z=0 plane. The OEPs together trace, or track, a 2D outline on the Z=0 plane of the image captured by the camera 12. Depending on the shape and configuration of the inspected object, there may be one or more sets of OEPs, each set relating to a respective interior or exterior perimeter of the inspected object. For example, for the object 24, there are four sets of OEPs, one set for the exterior perimeter and three respective sets for each of the apertures 26. The tasks represented by blocks 206 and 208 may be performed simultaneously.

However, it is not possible to determine from the OEPs alone whether a given OEP relates to an upper or lower

edge of the inspected object. To address this problem, the or each set of OEPs is assumed to define a respective polyline. For each OEP, the data processing module 16 is arranged to calculate one or more respective parameters relating to, or defining, the respective normal to the polyline at each OEP (Figure 2, block 210). In the preferred embodiment, this is achieved by calculating a respective parameter in the form of the value of the respective angle between a reference axis and the respective normal. In order to make consistent calculations, a reference system must be established. It is therefore assumed, by way of example, that the reference axis from which angles in the X-Y plane are measured comprises, or is parallel with, the X-axis, and that angles are measured in an anti-clockwise direction from the reference axis. It is also assumed, by way of example, that the normal to the polyline at any given OEP extends inwardly of the object 24, 24′ (i.e. inwardly of the polyline if the polyline represents an exterior perimeter, and outwardly of the polyline if the polyline represents an interior perimeter).

There are many suitable conventional methods for calculating normals and or parameters that are indicative thereof. For example, with reference to Figure 3, there is shown an example of a polyline 301 defined by a plurality of OEPs. The normal of a given point OEP2 may be assumed to comprise a line which bisects the angle A formed between the respective sections 303, 305 of polyline 301 which join the point OEP2 to its nearest neighbours OEP1, OEP3 on either side. Since the respective 2D co-ordinates (in the X-

Y) plane OEP1, OEP2 and OEP3 are known, angle A may readily be calculated. In the preferred embodiment, the normal N2 at OEP2 is represented by parameter NA2 which is the angle between the reference axis and the normal N2. Assuming that the normal N2 bisects angle A, then angle NA2 = 180 - (A/2). It is noted that in Figure 3 polyline 301 is assumed to represent an interior perimeter and, accordingly, the normal N2 is taken as extending outwardly of the polyline 301. If, alternatively, the polyline 301 was assumed to represent an exterior perimeter, then the normal N2 would extend inwardly of the polyline 301 and angle NA2 = 360 - A.

It will be appreciated that, when calculating the respective angles between the reference axis and the normals (hereinafter referred to as "normal angles"), the data processing module 16 needs to know if the respective OEP being processed belongs to an interior perimeter or an exterior perimeter. This may conveniently be determined during or after the tasks described in relation to block 204. Some edge detection and/or data sorting algorithms (blocks 202, 204) determine automatically whether a set of edge points relate to an interior or exterior perimeter. This is, in any event, simple to deduce by comparing the respective edge point values in each set.

The data processing module 16 further calculates the respective position of each OEP with respect to a point $FP_{x,y}$ which is the projection of the camera's focal point onto the Z=0 plane along a line which is perpendicular to the Z=0 plane, i.e. a projection of

the camera's focal point perpendicularly onto the Z=0 plane. In the present embodiment, this corresponds with the point at which the camera's normal line of sight 13 intersects the Z=0 plane. This is illustrated in Figure 5.

In Figure 5, there is shown a simplified object 24' under inspection. The object 24' has an aperture 26' formed therein. After block 208 (Figure 2), the object 24' is represented by two sets of OEPs, one set corresponding to the exterior perimeter of the object 24' (represented in Figure 5 as emboldened polyline P1), the other set corresponding to an interior perimeter (represented in Figure 5 as emboldened polyline P2) representing aperture 26'. For illustration purposes; two OEPS, namely OEP4 and OEP5 on interior polyline P2 are highlighted, the former being from the top edge of aperture 26', the latter being from the bottom edge aperture 26' (the relative terms "top" and "bottom" being taken with respect to the Z=0 plane and wherein increasing height is indicated by an increase in the value of the Z co-ordinate). The respective normals N4, N5 for OEP4 and OEP5 are shown extending outwardly from the polyline P2. The projected focal point of the camera 13 onto the Z=0 plane is shown as $FP_{x,y}$. The data processing module 16 notionally constructs a respective radial line R4, R5 extending between the projected focal point $FP_{x,y}$ and OEP4, OEP5 respectively. In respect of each radial line R4, R5, the data processing module 16 calculates (block 212) a respective angle RA4, RA5 between the reference axis and the radial line (hereinafter referred to as the radial angle). The

radial angles are readily calculated from the known 2D co-ordinates (in the X-Y plane) of the projected focal point $F_{x,y}$ and the respective OEP.

Then, at block 214, the data processing module 16 compares the respective normal angle NA4, NA5 with the respective radial angle RA4, RA5. If the absolute difference between respective normal and radial angles is less than 90 degrees (as is the case for RA5 and NA5) then the data processing module 16 determines that the OEP relates to a bottom edge (block 220). If the absolute difference between respective normal and radial angles is greater than 90 degrees (as is the case for RA4, NA4) then the data processing module 16 determines that the OEP relates to a top edge (block 216). If the angle is deemed to be equal to 90 degrees, then an assumption can be made that the OEP relates to either the top edge or the bottom edge, as desired.

If an OEP is identified as belonging to a bottom edge, then a corresponding 3D point for creating a 3D model of the object 24, 24′ is created having the same X and Y co-ordinates as the respective OEP and with Z=0 as the third dimension (block 222).

If an OEP is identified as belonging to a top edge, then conventional mathematics may be employed to calculate a corresponding 3D point for creating a 3D model of the object 24, 24′. This will become apparent upon consideration of Figure 4. Figure 4 shows an object 24, 24′ located on a work surface 28, 28′. It is desired to calculate the position in 3D of the

actual edge point AEP of the object 24, 24'. The line of sight LOS from the camera's focal point is shown in dashed outline. The X and Y co-ordinates (OEP_X, OEP_Y) of the corresponding OEP are known, so too is the height FP_Z of the focal point. The thickness T of the object 24, 24' is also known. Hence, the X and Y co-ordinates of the actual edge point AEP (AEP_X, AEP_Y) can be calculated using simple geometry and so the 3D position of the actual edge point AEP can be determined (block 218). For example, in Figure 4, the X co-ordinate AEP_X may be calculated using the equation

$$AEP_X = OEP_X - ((OEP_X/FP_Z)*T)$$

The Y co-ordinate AEP_Y may be calculated by substituting the OEPY value instead of OEP_X into the above equation. The Z co-ordinate AEP_Z of the actual edge point AEP is equal to the thickness T of the object 24, 24'.

The operations described with reference to blocks 206 to 218 or 222 may be repeated for each OEP as is necessary.

Hence, a 3D real world co-ordinate can be calculated for each OEP on a detected perimeter using only the data captured from a single image of the object 24, 24'. These 3D co-ordinates may be used to build up a 3D model of the object 24, 24'. If desired, or where necessary, conventional data fitting techniques may be used to deduce the true shape of the object 24, 24' or parts, e.g. apertures, thereof from the detected perimeters.

It will be apparent that the techniques described above may be applied to any edge point at which the thickness of the object 24, 24′ is known. This does not necessarily imply that the object under inspection is of generally uniform thickness.

In the foregoing description, it is assumed for illustrative purposes only that the object 24, 24′ under inspection is right-sided, i.e. that the sides of the object 24, 24′ are substantially perpendicular with its faces and therefore, in the present example, lie in a plane that is substantially perpendicular to the X-Y plane. The invention may equally be used with objects (not shown) that are not right-sided. This is now illustrated by way of example with reference to Figures 6 to 12.

In the following description referring to Figures 6 to 12, the acronym ICS refers to the image co-ordinate system (with includes the image plane of the camera) and points in the ICS (including points in the image plane, e.g. IEPs) are referred to as PICs. The acronym WCS refers to the world co-ordinate system, i.e. the real world XYZ co-ordinate system in which, in the present example, the object plane corresponds with the Z=0 plane. Points in the WCS system (which include points in the object plane, e.g. OEPs) are referred to as PWCs.

Figures 6 and 7 show, by way of example only, two basic types of edge angle that a typical object under

inspection may have, namely a bevelled edge (Figure 6) or an undercut edge (Figure 7).

Figure 8 shows a plan view of an object with an angled edge. The top and the bottom edges are visible and indicated. Both edges are assumed to be parallel. A line of sight is projected from the focal point, both the line of sight and the focal point are shown and indicated. The absolute difference between the line of sight angle and the top or bottom edge normals (PWC Normal Angle) is greater than 90 degrees, therefore the edge is currently assumed to be a top edge. $dW_{x/y}$ are the x and y distances (in the X/Y plane) from the top of the edge to the bottom of the edge along the line of sight.

A cross-section normal to the object's edge is indicated. The cross-section's horizontal axis is along the PWC Normal Angle and the cross-section's vertical axis is the Z-axis. This cross-section is shown in Figure 9.

In Figure 9, both the Object Edge Angle (OEA) and Edge Width are shown and are required to be known in advance. Either can be calculated from the object thickness and the other, e.g. the object thickness and Edge Width could be used to obtain the OEA.

The next angle required is the Line of Sight Angle (LoSEA). The LoSEA is in the same plane as the OEA. The Focal Point x/y position, the PWC Normal Angle, the $PWC_{x/y}$ value, and the PWC Radial Angle, are all are

assumed to be known. Only some of the values are needed to calculate the LoSEA.

If, as shown in Figure 9, the OEA is less than the LoSEA, the new rule overrides the previous assertion that the edge point was created from the top of the object, and the PWCx/y point is actually from the bottom of the object. Hence:

Final $PWC_{x/y}$ value = Initial $PWC_{x/y}$ value

If OEA is greater than the LoSEA, as shown in Figure 10, it is confirmed as being from the top of the object, as is the case in Figure 10, and the PWCx/y value must be amended using the following formulae.

$PWC_{x/y}$ value =

$PWC_{x/y}$ value – (($PWC_{x/y}$ value/Focal Point WCS z height) * Thickness) + $dW_{x/y}$

$dW_{x/y}$ is indicated in Figure 1.

$dW_{x/y}$ is the change in position due to edge width in the x and y directions. The Focal Point x/y position, the PWC Normal Angle, the $PWC_{x/y}$ value, and the PWC Radial Angle, are all are assumed to be known. Only some of the values are needed to calculate the $dW_{x/y}$.

Figure 11 shows a flow chart illustrating how the data processing module 16 may perform the calculations described above. It will be noted that the illustrated algorithm is the same as the algorithm illustrated in Figure 2 until the point where it is determined that the PIC is a top edge.

This algorithm can easily be adapted to handle OEAs which are undercut. In these circumstances it should be pointed out that the minimum edge position is the edge position which is of interest. E.g. when considering a hole which is either bevelled or undercut, the maximum size cylinder which can fit through the hole is the measurement of interest.

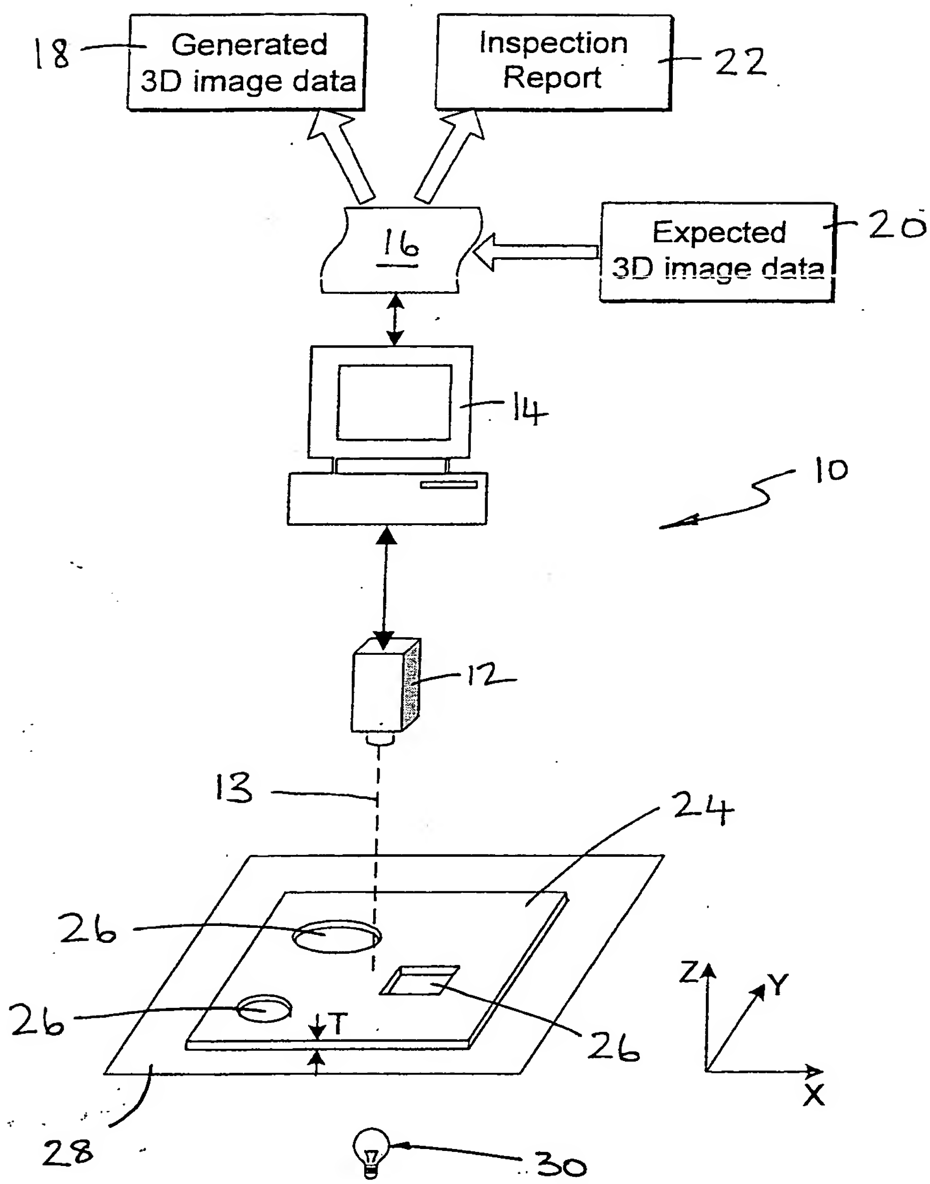
Figure 12 shows a flow chart illustrating how the data processing module 16 may perform the calculations for an undercut edge. It will be noted that the illustrated algorithm is the same as the algorithm illustrated in Figure 2 until the point where it is determined that the PIC is a bottom edge.

It will be understood that the invention is not limited to the specific calculation techniques described herein as at least some aspects of the calculations are dependent on the selected reference system, e.g. the selected direction of the normal and the angle measuring references. Further, it is not essential that the normal from an OEP be used as a reference representing the OEP. For example, the tangent from an OEP may alternatively be used as a reference representing the OEP. Equally, any other line from an OEP may be used as a reference so long as the selected reference line is used consistently for each OEP. A skilled person will appreciate that selecting an alternative reference will affect the subsequent calculations. For example, the calculation at stage 214 of Figure 2 may become:

$$\mathrm{Abs}(\text{Radial Angle} - \text{Reference Angle}) > (90 + \theta)$$

Where "Reference Angle" is the angle made between the angle reference axle and the selected reference line, and θ is the angle between the normal and the reference line measured from the angle reference axis.

The invention is not limited to the embodiment described herein which may be modified or varied without departing from the scope of the invention.



18
Generated 3D image data
Inspection Report
22
16
Expected 3D image data
20
14
10
12
13
24
26
26
T
26
Z
Y
X
28
30

Fig. 1

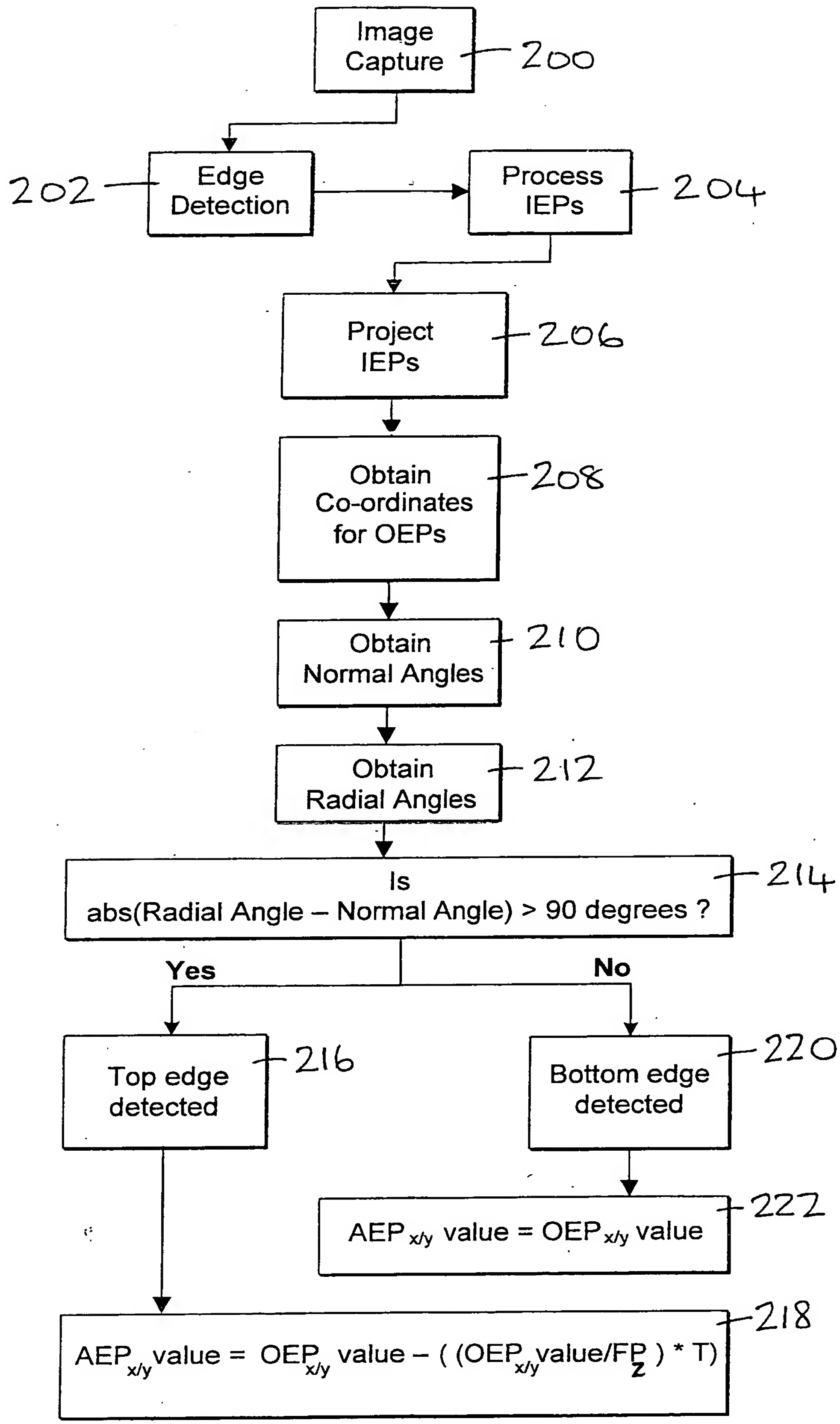


Image Capture
200
202
Edge Detection
Process IEPs
204
Project IEPs
206
Obtain Co-ordinates for OEPs
208
Obtain Normal Angles
210
Obtain Radial Angles
212
Is abs(Radial Angle – Normal Angle) > 90 degrees ?
214
Yes
No
Top edge detected
216
Bottom edge detected
220
AEP$_{x/y}$ value = OEP$_{x/y}$ value
222
AEP$_{x/y}$ value = OEP$_{x/y}$ value – ((OEP$_{x/y}$ value/FP$_{Z}$) * T)
218

Fig. 2

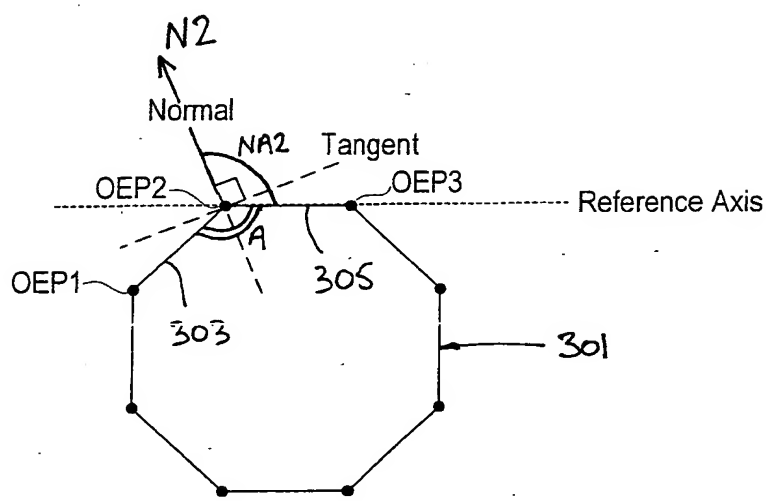

N2
Normal
NA2
Tangent
OEP2
OEP3
Reference Axis
A
OEP1
305
303
301

Fig. 3

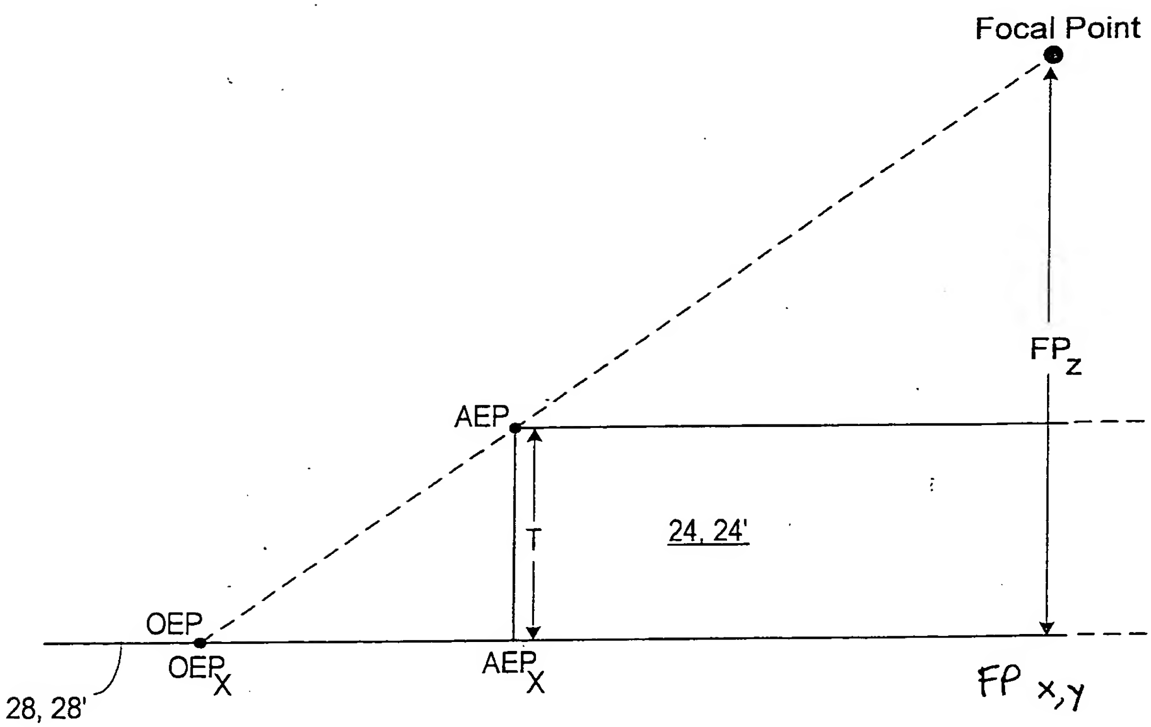

Focal Point
FPz
AEP
T
24, 24'
OEP
OEPX
AEPX
FP x,y
28, 28'

Fig. 4

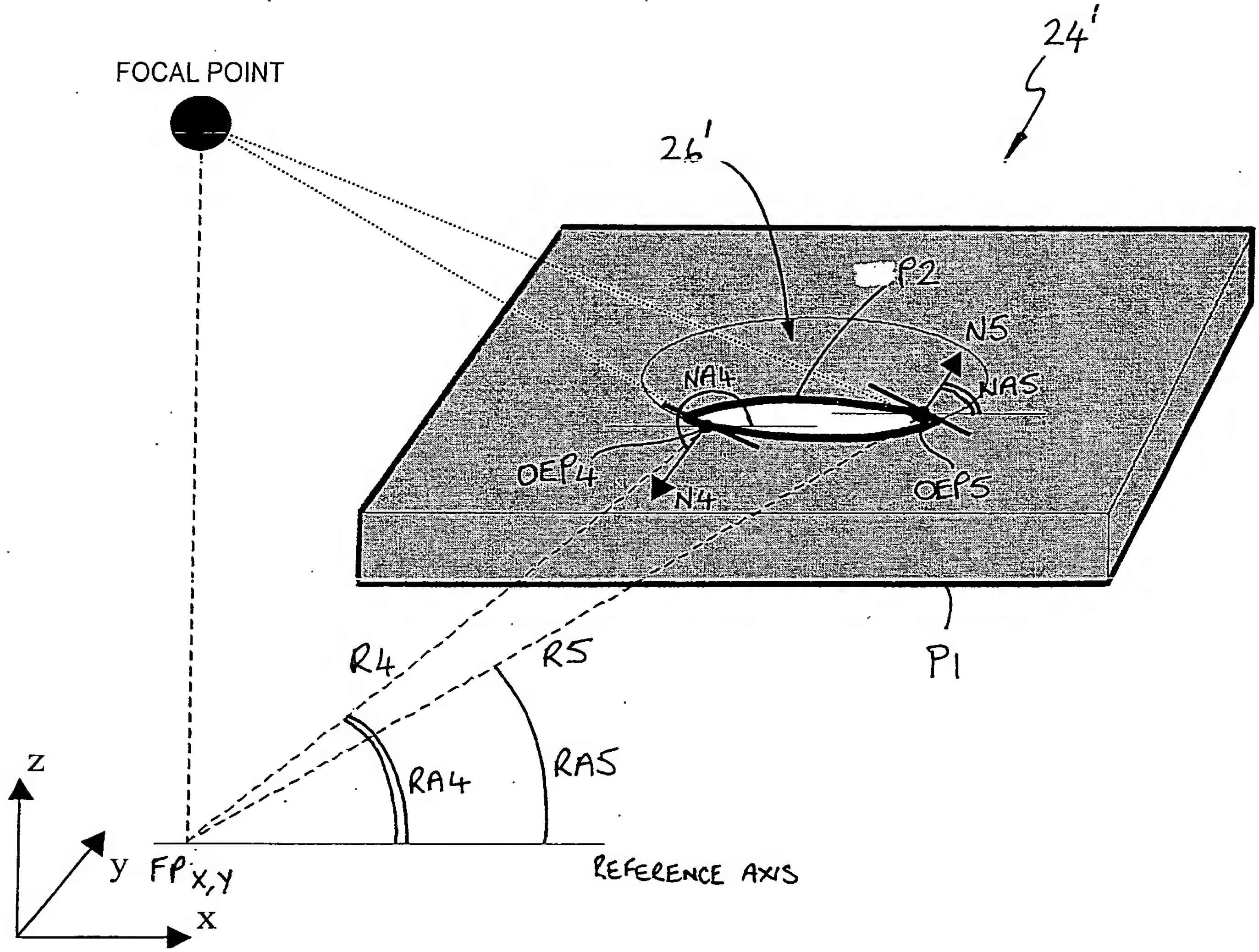

FOCAL POINT
24'
26'
P2
N5
NA4
NA5
OEP4
N4
OEP5
P1
R4
R5
RA4
RA5
z
y
x
FP x,y
REFERENCE AXIS

Fig. 5

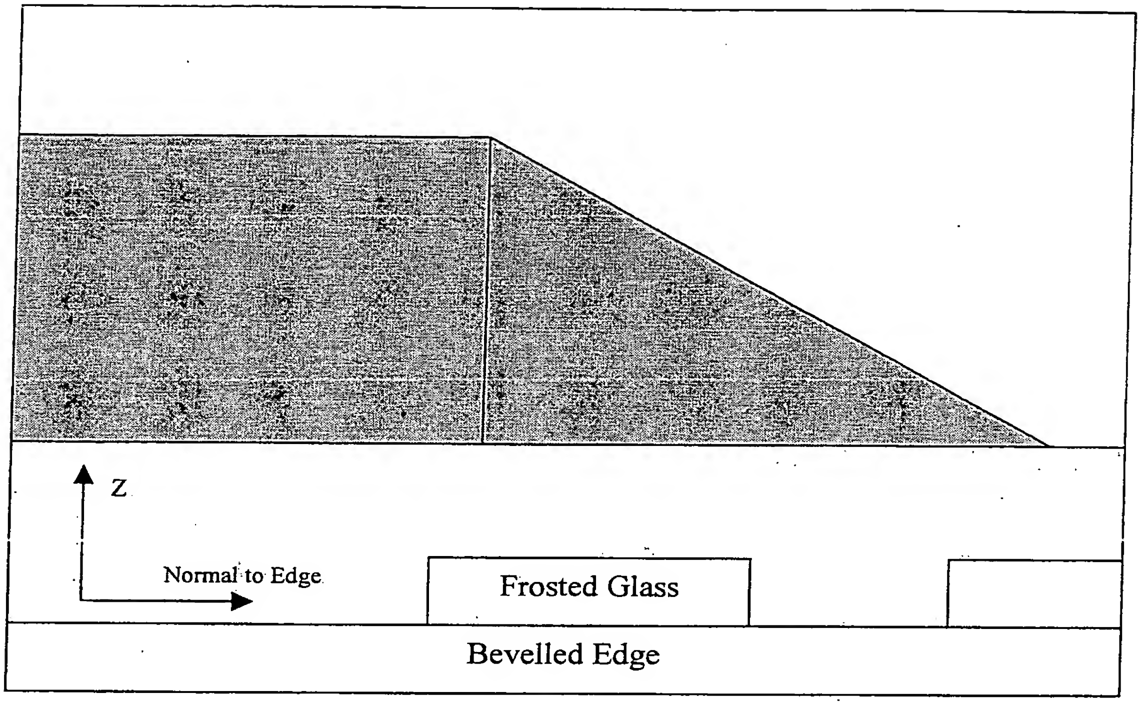

Z
Normal to Edge
Frosted Glass
Bevelled Edge

Fig. 6

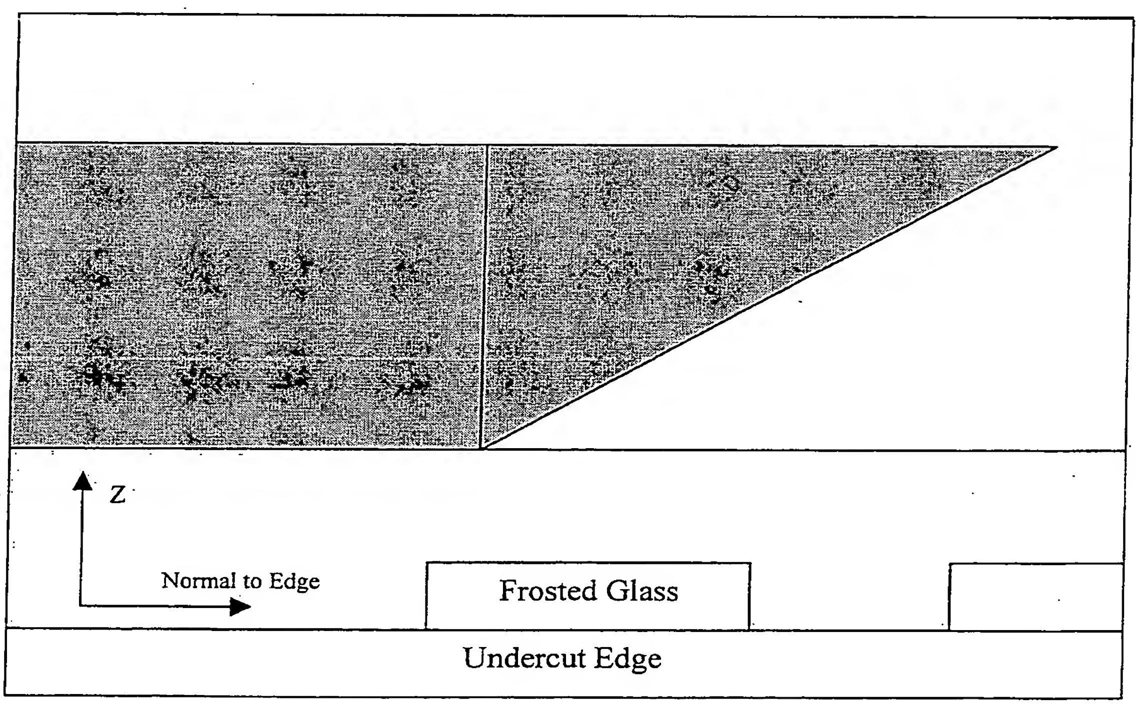
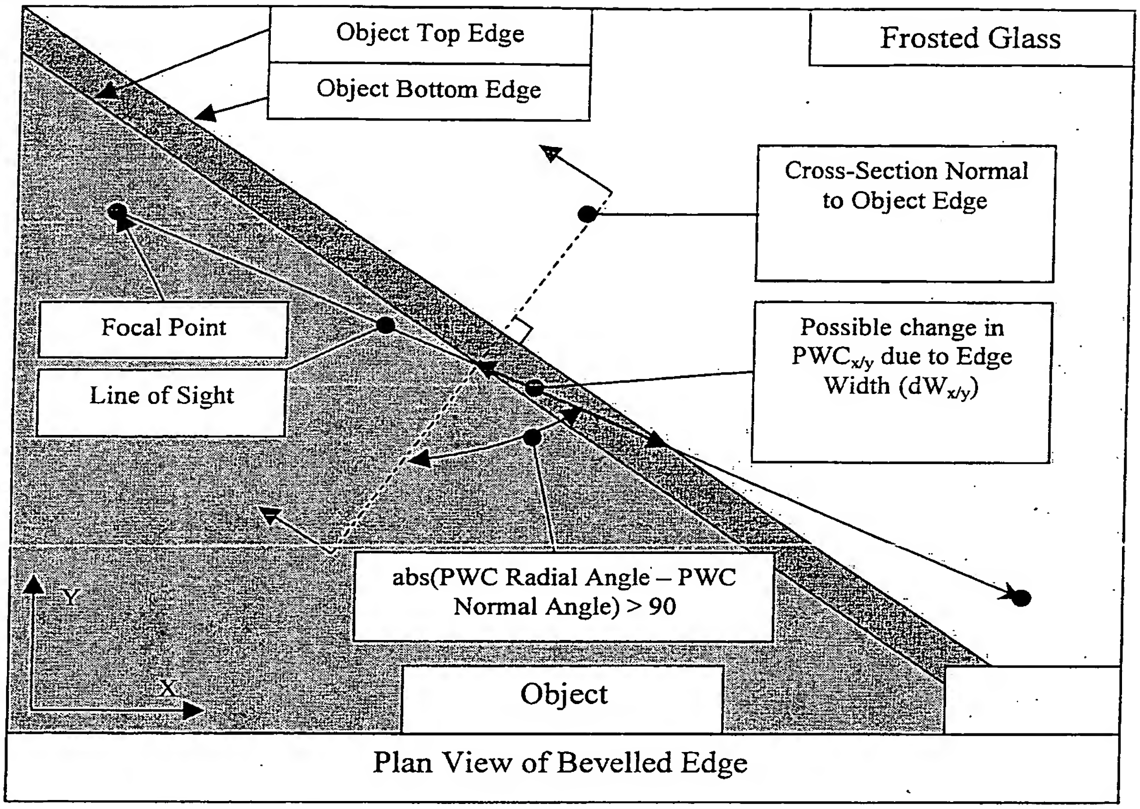
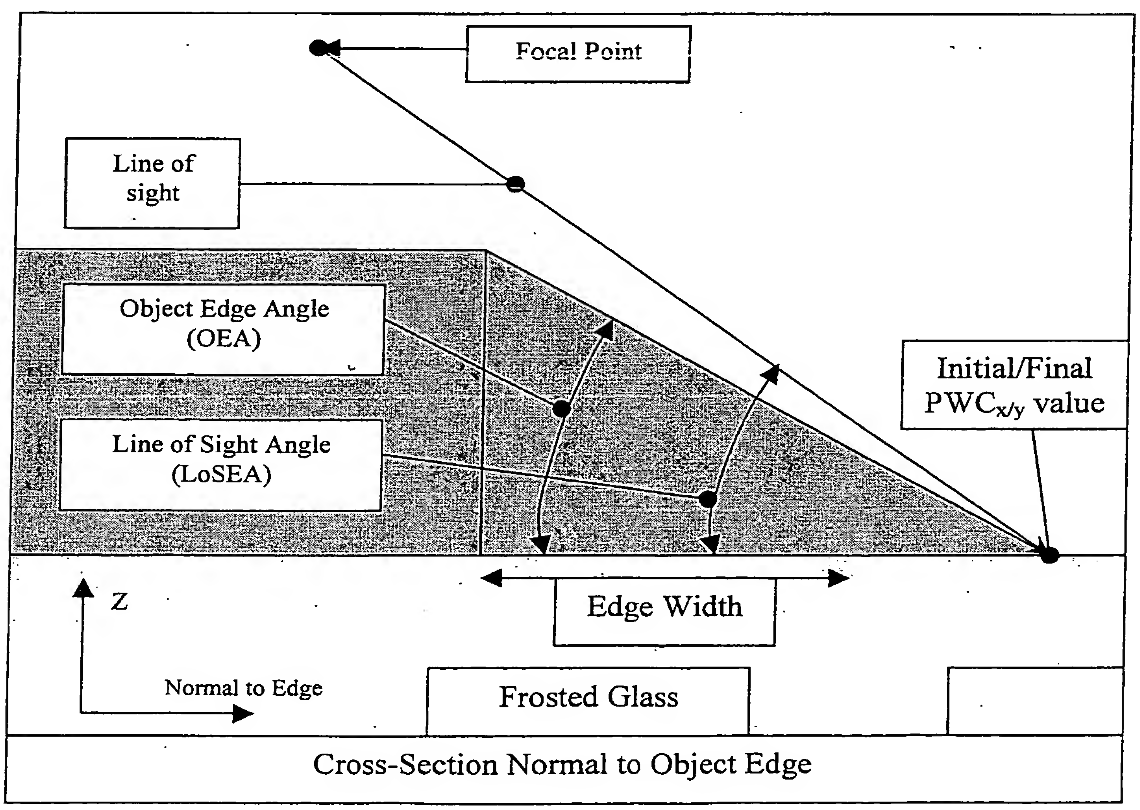

Z
Normal to Edge
Frosted Glass
Undercut Edge

Fig. 7



Object Top Edge
Object Bottom Edge
Frosted Glass
Cross-Section Normal to Object Edge
Focal Point
Line of Sight
Possible change in $PWC_{x/y}$ due to Edge Width ($dW_{x/y}$)
abs(PWC Radial Angle – PWC Normal Angle) > 90
Y
X
Object
Plan View of Bevelled Edge

Fig. 8



Focal Point
Line of sight
Object Edge Angle (OEA)
Line of Sight Angle (LoSEA)
Initial/Final $PWC_{x/y}$ value
Z
Edge Width
Normal to Edge
Frosted Glass
Cross-Section Normal to Object Edge

Fig. 9

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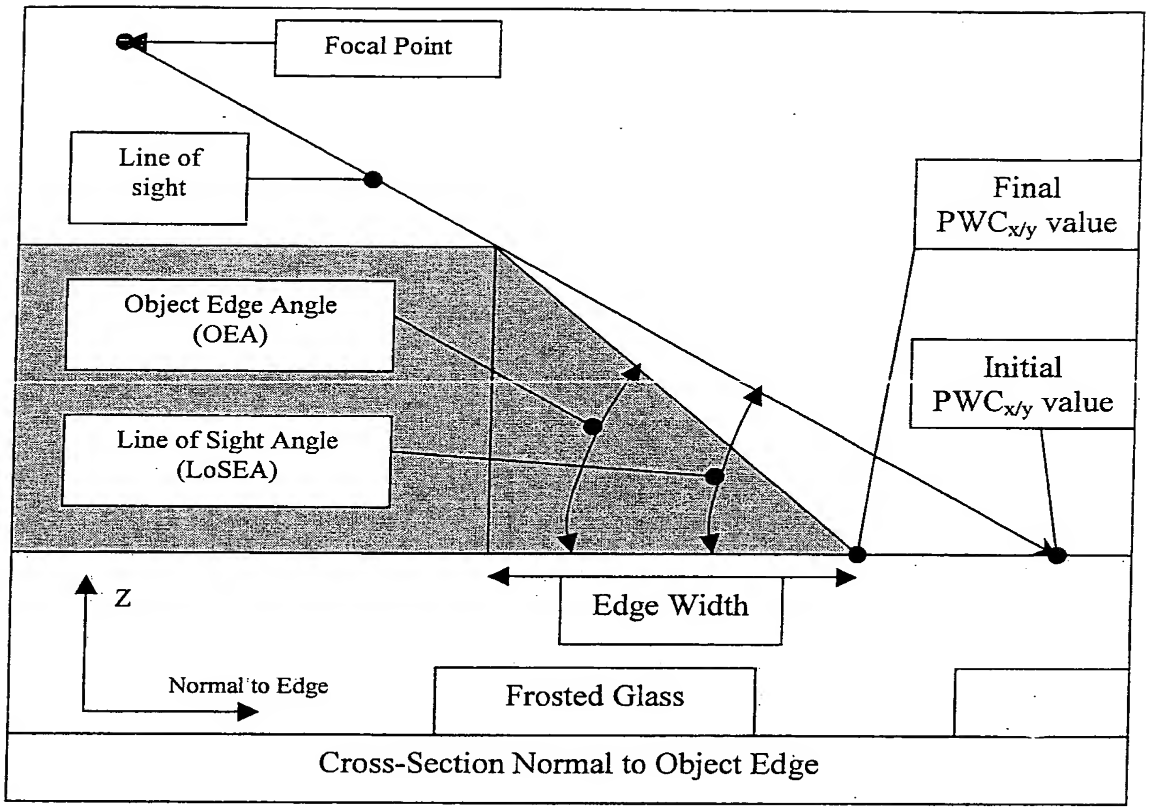

Focal Point
Line of sight
Final PWCx/y value
Object Edge Angle (OEA)
Initial PWCx/y value
Line of Sight Angle (LoSEA)
Z
Edge Width
Normal to Edge
Frosted Glass
Cross-Section Normal to Object Edge

Fig. 10

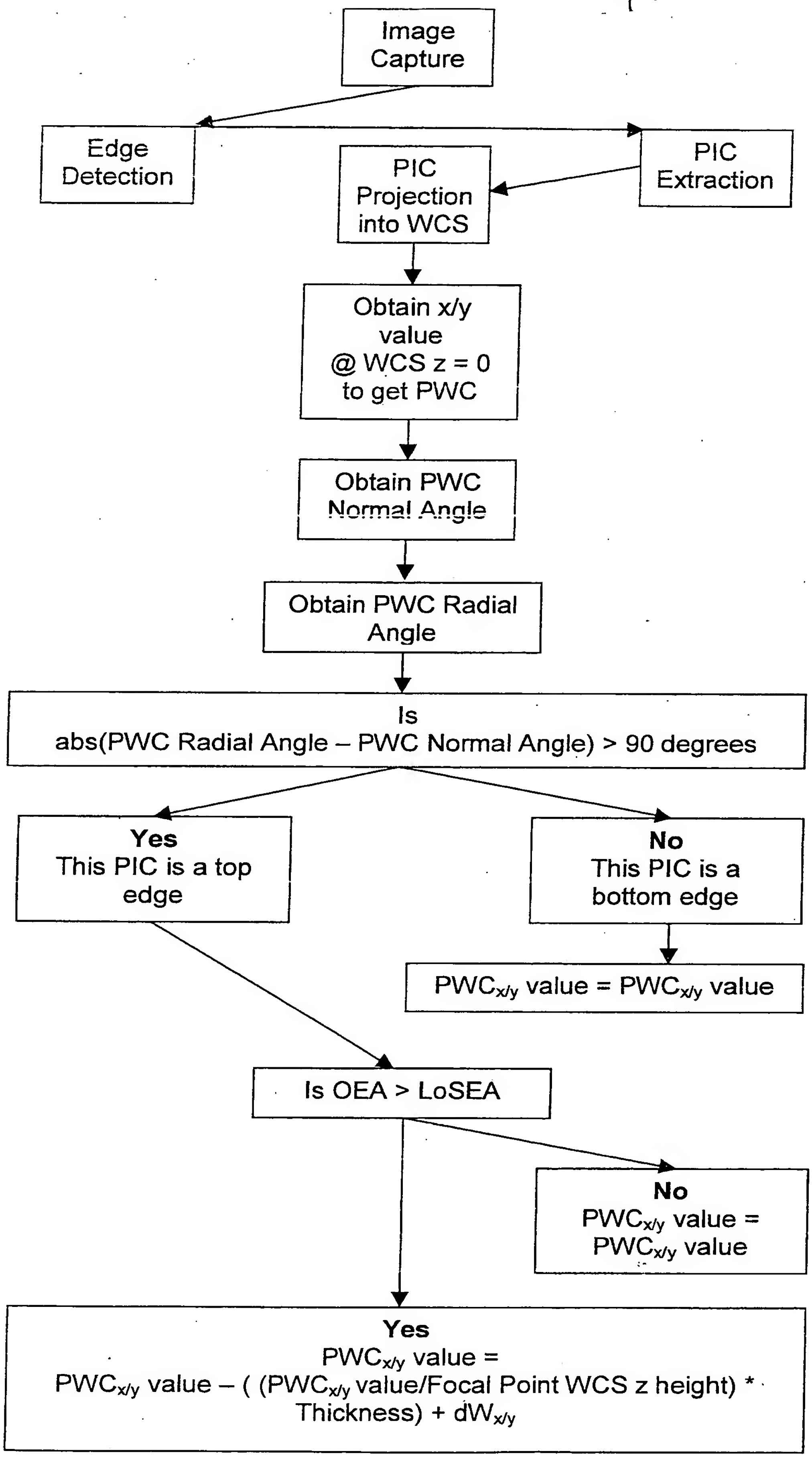
Image Capture
Edge Detection
PIC Extraction
PIC Projection into WCS
Obtain x/y value @ WCS z = 0 to get PWC
Obtain PWC Normal Angle
Obtain PWC Radial Angle
Is abs(PWC Radial Angle – PWC Normal Angle) > 90 degrees
Yes This PIC is a top edge
No This PIC is a bottom edge
PWCx/y value = PWCx/y value
Is OEA > LoSEA
No PWCx/y value = PWCx/y value
Yes PWCx/y value = PWCx/y value – ((PWCx/y value/Focal Point WCS z height) * Thickness) + dWx/y

Fig. 11

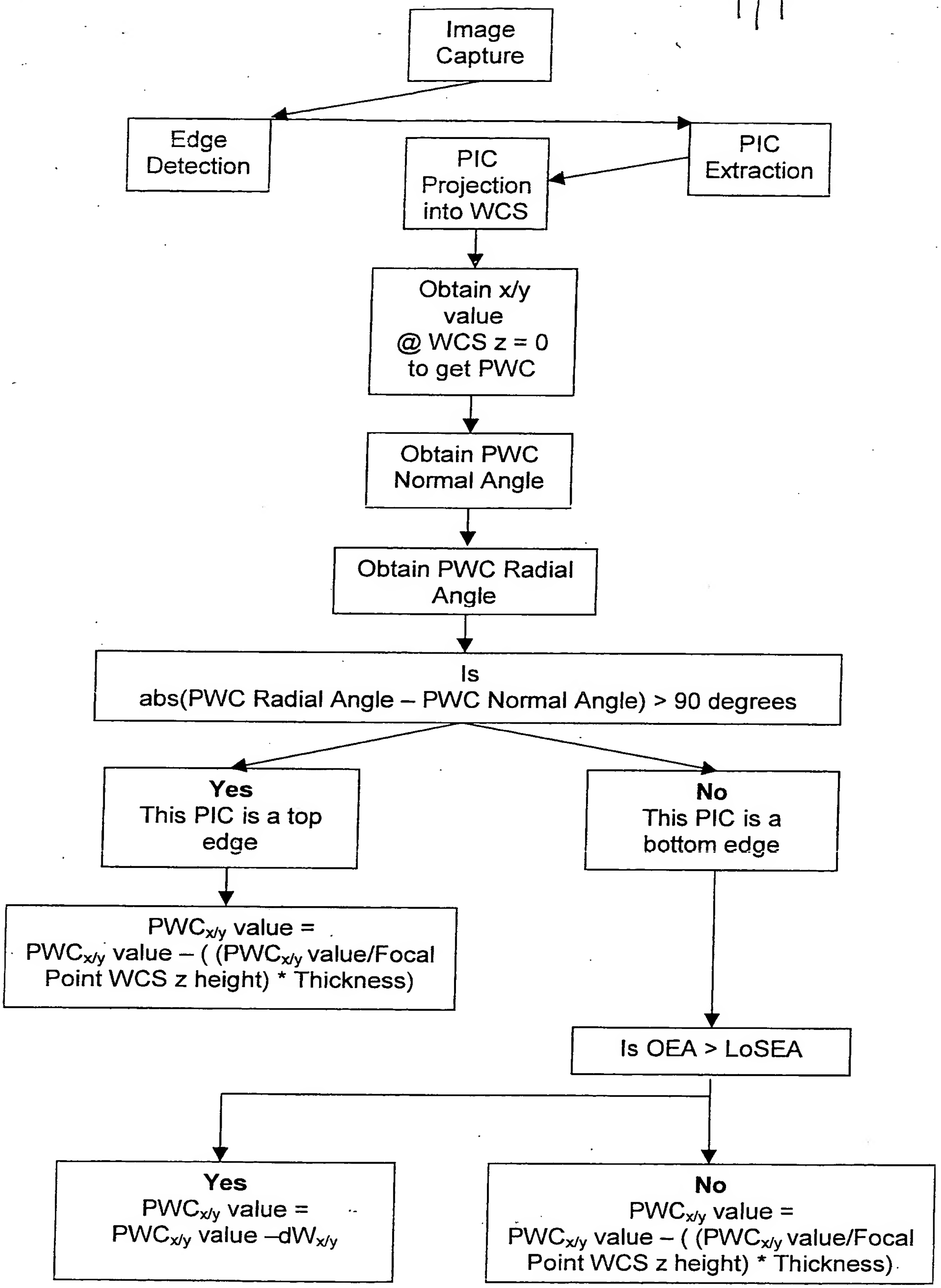
Image Capture
Edge Detection
PIC Extraction
PIC Projection into WCS
Obtain x/y value @ WCS z = 0 to get PWC
Obtain PWC Normal Angle
Obtain PWC Radial Angle
Is abs(PWC Radial Angle – PWC Normal Angle) > 90 degrees
Yes This PIC is a top edge
No This PIC is a bottom edge
$PWC_{x/y}$ value = $PWC_{x/y}$ value – (($PWC_{x/y}$ value/Focal Point WCS z height) * Thickness)
Is OEA > LoSEA
Yes $PWC_{x/y}$ value = $PWC_{x/y}$ value $–dW_{x/y}$
No $PWC_{x/y}$ value = $PWC_{x/y}$ value – (($PWC_{x/y}$ value/Focal Point WCS z height) * Thickness)

Fig. 12